# NATIONAL POWER GRID SIMULATION CAPABILITY: NEEDS AND ISSUES

*A Report from the National Power Grid Simulator Workshop, December 9-10, 2008 • Argonne, Illinois*

*U.S. Department of Homeland Security, Science and Technology Directorate*

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# National Power Grid Simulator Workshop

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*Science and Technology Directorate*

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# Summary

The Department of Homeland Security Science and Technology Directorate sponsored a two-day workshop in December 2008 to explore whether current electric power grid modeling and simulation capabilities are sufficient to meet known and emerging challenges. The workshop, which was hosted by Argonne National Laboratory, brought together forty power system and modeling experts from federal agencies, the national laboratories, and academia. At issue was whether a national power grid simulation capability could fill gaps that exist between today's efforts and the needs of decision and policy makers. The workshop identified barriers that a national grid simulation capability would need to overcome to be effective.

Modeling and simulation provide a computerized representation of the behavior of the grid system. They are used for developing an understanding of the interaction of the parts of an electric grid and of the system as a whole.

Modeling and simulation are an integral part of management, planning, and stewardship of the grid system. Modeling and simulation are used by a diverse set of stakeholders for a diverse set of applications, including operations, planning, training, and policymaking.

Despite the many ongoing quality electric power grid modeling projects, individual projects have been narrow in scope and have not provided an integrated, comprehensive capability. As a consequence, the workshop participants concluded that current efforts and capabilities at universities and national laboratories are inadequate for addressing important national-scale grid challenges, including:

- Wide-area disruptive events, including natural events, cascading accidents, and coordinated cyber and physical attacks.
- Interdependencies of the power grid system and critical infrastructures.
- Improvement of existing simulation methods.
- Planning and design scenarios for the power grids, including wide-scale deployment of intermittent, distributed generation.

Understanding the interdependencies of the electric power grids with other critical infrastructures, in particular, represents a serious unmet need. Disruptions in one infrastructure (such as the electric grid system) can have severe consequences for other infrastructures (such as the natural gas and water supply systems). Modeling and simulation are needed to understand the full impact of a regional or national-scale incident and would help improve recovery measures.

A national power grid simulation capability would be a key element toward filling these gaps to help ensure a resilient U.S. electric infrastructure. Such a capability would provide an advanced, scalable simulation environment that is open to federal, state, municipal, and industry users. It would provide an advanced user environment to simplify data and model integration, scenario construction, analysis, and report generation. The capability would be a resource for users akin to a Department of Energy user facility. In this sense, this would not be a *project* with specific deliverables, but a *capability* from which projects can be implemented.

A national power grid simulator capability would focus on U.S. electric power grid modeling and simulation with connections to other critical infrastructures, such as transportation, oil and natural gas, water supply, and communications. Such a capability would provide a simulation framework and suite of integrated simulation tools to support needs for security, reliability, and resiliency of the national power grids. The system would provide, for instance, a high-fidelity simulation environment for testing new models and evaluating the grid system's performance

and would help decision makers balance priorities for incident prevention and recovery. New modeling approaches could span diverse applications (operations, planning, training, and policymaking) and concerns (security, reliability, economics, resilience, and environmental impact) on a wider set of spatial and temporal scales than are now available.

A national power grid simulation capability would aim to support ongoing industry initiatives and support policy and planning decisions, national security issues and exercises, and international issues related to, for instance, supply chains, interconnectivity, and trade.

Such a capability does not exist today. A new initiative could fulfil this role, but would require a unique set of attributes:

- A multi-scale, multi-data, multi-user, multi-model system in a user-focused collaboration venue that allows coordination and interaction among users and stakeholders;
- Continuous improvements and capability enhancement;
- Flexible teaming and alliances; and
- Multidisciplinary tool-development teams.

For a national power grid simulation initiative to be effective, additional requirements would need to be met, including:

- Industry buy-in for the initiative;
- Cooperation among various government agencies responsible for grid operations, oversight, development, and security;
- Access to multiple levels of data, including possibly real-time data;
- Protective data sharing and legal measures associated with data and model access; and
- Validation of some model results with industry cooperation and support.

These features can be met through a combination of existing distributed capabilities and new capabilities. Defining the details of these needs will require further study.

Several issues would have to be addressed in developing and implementing a national power grid simulation capability. In particular, acquisition of and access to validated electric infrastructure data would be a necessary part of a grid simulator initiative. Physical and administrative protection of controlled information would be essential, including protection of sensitive information generated as model output. Additional issues related to data, models, computation, and result quality control are highlighted in this report.

Despite these issues, a national power grid simulation capability would provide many benefits, especially as the grid system faces new and growing challenges. In particular, a national power grid simulator would provide the opportunity for data sharing, data verification and validation, identification of data use, and an environment that simplifies the integration of diverse system models. A power grid initiative could also provide a template for eventually addressing a wider set of national issues such as water and waste water, communications, transportation, and other critical infrastructures.

For these reasons, the participants of the National Power Grid Simulator Workshop recommend a more detailed study of the barriers currently inhibiting the development of a national grid simulation capability. An operational plan that overcomes these barriers would set the stage for the implementation of a capability that would go far in supporting a more secure and reliable electric power grid system for the nation. A near-term step would be to further engage the electric power industry to better understand their needs, capabilities, and concerns.

# I. Introduction

On December 9 and 10, 2008, the Department of Homeland Security (DHS) Science and Technology Directorate sponsored a national workshop at Argonne National Laboratory to explore the need for a comprehensive modeling and simulation capability for the national electric power grid system. The workshop brought together leading electric power grid experts from federal agencies, the national laboratories, and academia to discuss the current state of power grid science and engineering and to assess if important challenges are being met. The workshop helped delineate gaps between grid needs and current capabilities and identify issues that must be addressed if a solution is to be implemented.

The electric power grid system is the heart of all critical U.S. infrastructures, including energy, communications, transportation, water, and food supply. The transmission system alone represents over 150,000 miles of line. Vulnerabilities of the power grid system are well documented. Indeed, the Department of Energy's 2002 National Transmission Grid Study estimated that "interregional transmission congestion costs consumers hundreds of millions of dollars annually." Zonal congestion in the Texas state power grid, as an example, cost $360 million for the first ten months of 2008, up from $52 million for the entire year of 2007.

Furthermore, the 2007 DHS-sponsored Power Grid Security study concluded, "the U.S. electrical power grid could be an attractive target for terrorist attack." The study went on to recommend that "improved capabilities for resilience, restoration, and recovery will be critical" and that "particularly important aspects are funding of demonstration projects and funding of modeling and simulation efforts."

In this context, a *model* is a simplified representation of a power grid at a particular location or point in time for understanding the real system. A *simulation* is the manipulation of a model to study the grid's changing behavior over time or space, thus enabling an analyst to perceive behavior that would not otherwise be apparent. Modeling and simulation, then, represent a discipline for understanding the interaction of the parts of an electric grid and of the system as a whole. They are an integral part of the management, planning, and stewardship of the grid system.

Although many quality electric power grid modeling projects have been done and are ongoing, individual projects have been limited in nature, addressing a narrow set of grid concerns, covering only a portion of the grid system, or relying on overly idealized assumptions. The two-day workshop at Argonne, Illinois, which was organized by a committee of nationally recognized experts (Appendix A), had forty participants (Appendix B). Together they identified national grid modeling and simulation needs that are not being met today and offered guidance toward meeting those needs.

The workshop program (Appendix C) included presentations and panel discussions on national grid concerns, current activities, and issues that a new national grid simulation initiative would face. Five breakout groups explored these issues in greater detail:

- Grid Simulation Research Portfolio,
- Models and Computation,
- Data and Results,
- Policy and Legal Issues, and
- User, Stakeholder, and Sponsor Coordination.

This report is a result of the workshop and highlights power grid modeling and simulation needs, the barriers that must be overcome to address them, and the benefits of a national power grid simulation capability.

# II. Background

The North American electric power transmission system includes four grids that have only limited connections between them: the Eastern Interconnection, the Western Interconnection, the Québec Interconnection, and the Texas Interconnection. The Central and Southeastern Alaska Interconnections are wholly separate and have no ties to the other grids. This system of interconnected electric transmission grew out of isolated systems designed for local customers. Interconnection allowed for the sharing of resources and more reliable power supply. The major interconnection systems were established in the 1960s; most of the contiguous United States and southern Canada were interconnected by the late 1960s.

Vulnerabilities of the power grid became evident, though, from events such as the Northeast Blackout of 1965, which initiated from a minor disturbance and cascaded through neighboring portions of the grid. This led to the Electric Reliability Act of 1967, which established regional reliability councils. The North American Electric Reliability Council [reorganized in 2007 as the North American Electric Reliability Corporation (NERC)] was established by the electric utility industry to work with the regional councils to develop common operating policies, training resources, and requirements.

Although system reliability has improved greatly over the past four decades, events such as the 2003 Northeast Blackout demonstrate that the grid is still subject to large-scale and costly disruptions. The grid will continue to grow and evolve as more distributed renewable energy generators are brought on line and as demand patterns shift. Moreover, vulnerabilities to the grid are likely to change, be they natural (e.g., as a result of climate change) or man-made (e.g., as a result of more sophisticated terrorist activities). These changes translate into a shifting set of operational and security challenges for the U.S. power grid.

## *National grid vulnerabilities*

The national power grids are composed of many components, each with its own range of vulnerabilities to both natural and man-made events. The most apparent components are the transmission lines that stretch unprotected across open countryside. Natural threats to these lines include wind, ice storms, and fires; potential man-made threats include rifle fire, bombs, chaff, and aircraft collisions. Isolated power line outages can be quickly repaired. The disruption of large numbers of lines or those located in special locations (e.g., across rivers and wide gaps), however, can be time-consuming to resolve.

Power generation equipment and substations form key nodes of the grid system. If a generator was severely damaged, it could take months or years to repair or procure a replacement. Much of the associated infrastructure, including many substations, lie out in the open with limited physical security.

One of the more serious ongoing concerns is the possibility of a cyber attack. Control centers and supervisory control and data acquisition (SCADA) systems are critical to the flow of power through the grids. Hacking and manipulation could cause a major grid failure.

## *Emerging issues*

There are currently many federal and state legislative efforts to increase the percentage of power derived from renewable sources and reduce carbon-intensive generation. Many states now have goals for as much as 30 percent renewable power by 2030. Federal plans call for 20 percent by 2030. Renewable power generation depends largely on local conditions (e.g., wind or sunlight availability). The best locations for production are often not where the greatest power demands are. Power transmission, then, could be a limiting factor in the growth of distributed, renewable energy generation.

Some studies suggest that when intermittent power sources such as wind and solar reach penetration levels as low as 2 to 3 percent of the overall generation mix, grid instability can result. Recent disruptions in Texas, for instance, were attributed to rapid fluctuations in wind power. The Electric Reliability Council of Texas, Inc. (ERCOT) estimated that zonal congestion costs increased seven times from 2007 to 2008. A major contributor has been the growth in wind generation with an inadequate ability to ship the power to load centers. Meanwhile, ERCOT is reviewing plans to increase Texas wind capacity by nearly a factor of ten. The incorporation of large amounts of distributed and intermittent power sources in Texas and elsewhere will likely require significant changes to the way the grid is operated.

One suggestion has been to build a power grid superhighway that would ship large amounts of power long distances through major trunk lines, avoiding the circuitous path of local lines that power now moves through. The system would help transport renewable power from remote generation sites to regions of high demand.

Complicating these other trends, grid operations will need to address a Congressional push for plug-in hybrid electric vehicles, and smart grid technologies will alter demand patterns which grid operators will need to address. Congress could potentially mandate changes in the way utilities manage their systems.

With all these emerging changes, the national power grid system, its operations, and its response to perturbations may look very different than they have in the past.

# III. Current Grid Research, Modeling, and Simulation

Industry, universities, and federal laboratories have devoted much effort to the development of sophisticated computer models for various electric power grid applications. This chapter provides a cursory look at modeling approaches and software products. The survey points to a lack of high-fidelity models capable of simulating national-level grid scenarios. An early step in the planning of a national grid simulation capability, however, would be to work with the electric power industry to further explore the range of modeling tools they have developed internally.

Power system simulation models are used by a variety of stakeholders including utilities, policymakers, researchers, and security agencies. Utilities use models to plan long-term expansion projects, formulate short-term operating strategies, and manage real-time operations. Transmission operators require models to guide the operation of the transmission system and the efficient dispatching of generating units. Power cooperatives use modeling to assure competitive rates for their members. Policymakers are interested in examining possible effects of proposed policies prior to their implementation. Academic and industry researchers seek to improve modeling techniques, achieve faster solutions, and enhance result visualizations. Government agencies such as the Department of Homeland Security (DHS) and the Department of Energy (DOE) look at operability, vulnerability, threat, and recovery assessment issues related to grid operations.

Modeling applications include the following:

- *Planning* models are normally used for modeling long-term capacity expansion, but are also used for evaluating policy measures proposed for the energy sector.
- *Operational support* models are designed to support real-time operations or short-term operational planning and reliability assessments, as well as for operator training.
- *Resiliency assessment* models simulate processes and dynamics associated with maintaining system continuity or restoring power after failures caused by disturbances such as earthquakes, severe weather, or major component failures.
- *Power market analysis* models simulate the interactions between market participants and stakeholders in electric market environments.
- Certain specially-designed models are used to identify and assess *critical assets* of power systems in terms of consequence-of-loss criteria when the system is subjected to various disturbances.

Current grid modeling and simulation efforts are often piecemeal, because the individual projects tend to focus on a narrow set of issues. Although large-scale efforts through organizations such as regional transmission organizations (RTOs) and independent system operators (ISOs) are beginning to address broader issues, the scope of such efforts has yet to address national concerns.

### *Modeling approaches and tradeoffs*

Modeling approaches attempt to balance costs and benefits such as representation, scope, complexity, data requirements, processing speed, and adequacy of expected results.

Mathematical formulation is an important consideration in model selection, because it has significant implications on solution requirements, computer memory and speed requirements, and overall complexity. Attributes that affect model complexity include:

- Linear vs. nonlinear;
- Discrete vs. continuous;
- Static vs. dynamic;
- Plain simulation vs. directed (constrained) optimization;
- Probabilistic vs. deterministic;
- Aggregated (equivalent) vs. disaggregated (detailed) network and component representations;
- Regional (e.g., pools, control areas, independent system operators, or utilities) vs. national scope; and
- Agent-based vs. conventional modeling approaches.

As one example of methodological tradeoffs, linear models are often used for screening analyses. They give only approximate results, but require fewer input data, simpler mathematical algorithms, and shorter run times than their nonlinear counterparts.

The data requirements for models increase as model complexity increases. Models with a broad scope (e.g., operations with economic impacts) require more types of data. In contrast, models that offer greater granularity (i.e., address more operational details) require a deeper level of data.

## EXAMPLES OF ONGOING EFFORTS

### *Industry and industry organizations*

Industry stakeholders include electric utilities, utility associations, the North American Electric Reliability Corporation (NERC), and the Electric Power Research Institute (EPRI). Most utilities use off-the-shelf or customized commercial software for planning, operations, and reliability and power market assessments, though some have developed their own software. The power industry's extensive expertise in grid operations and supply/demand dispatch and control supplements their use of computer models in conducting sophisticated analyses of grid behavior.

Some initiatives from EPRI include IntelliGrid and Fast Simulation and Modeling (FSM). In addition, the GridWise Alliance is a consortium of public and private stakeholders focused on building an integrated approach to improving existing systems and technologies.

### *Commercial*

The commercial sector generates simulation models for the industry. For example, software from Siemens Power Technology International (PTI) covers most aspects of system operation and planning. Other well-known developers are Asea Brown Boveri (ABB), GE, Power Tech Inc, ERA Technologies, and PowerWorld.

Commercial models are generally intended for operational planning, operator training, and reliability assessment. More market-oriented models have also emerged.

### *Department of Energy national laboratories*

Models developed by U.S. Department of Energy (DOE) national laboratories tend to be specialized, addressing homeland security (e.g., vulnerability and threat assessments), renewable energy accommodation, system restoration (e.g., self healing and smart grid), interdependencies, power market responses, service area and outage area determination, and asset protection.

### *Academia*

Most electric grid simulation models being developed by academia are research-oriented. Most of these models are limited in scope, usually confined to pilot studies involving 30- to 64-bus systems. Objectives include testing new modeling approaches, new mathematical formulations, or novel solution algorithms.

## NEED FOR NATIONAL, COMPREHENSIVE SIMULATION

Current power grid models are generally applicable to problems at the regional, control area, power pool, or utility level. There is, in general, a lack of a simulation capability and associated data for national-level studies. For instance, large-scale dynamic transient stability models do not exist, though large-scale linear load flow models do.

An all-encompassing national model could address the integration of the various electric operating entities that make up the grid system. More realistically, though, a suite of power system simulation tools could be used to layer models of varying scope, capability, granularity, and timescales. Such integrated structures would allow for seamless exchange of data among the various tools in the suite, flexibility in accommodating varying geographical scope of the network, and adjustments of solution methodology in response to problem complexity or granularity requirements.

A national power grid simulator capability would focus on U.S. electric power grid modeling and simulation with connections to other critical infrastructures, such as transportation, oil and natural gas, and communications. Such a capability would provide a simulation framework and suite of integrated simulation tools to support the needs for security, reliability, and resiliency of the national power grid system. The resource would provide, for instance, a high-fidelity simulation environment for testing new models and evaluating the grid system's performance and would help decision makers balance priorities for incident prevention and recovery.

A national power grid simulator capability would support policy and planning decisions, national security issues and exercises, and international issues related to, for example, supply chains, interconnectivity, and trade.

Power grid models can be classified along three dimensions (Figure 1): operations, planning and evolution, and disruptions. The operation axis includes models for state estimation, planned and unplanned outage management, contingency analysis, and market prediction.

These applications are particularly useful to the power industry, which is interested in management of today's grids. The planning and evolution axis focuses on long-term planning and technology integration into an evolving grid system. This can include changes in the proportion of distributed, renewable generation and smart grid technologies. The disruption axis includes models dealing with threats, cascade scenarios, and natural and man-made disasters and events.

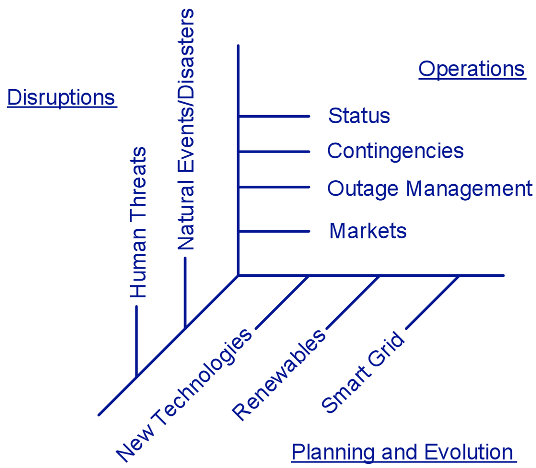



*Figure 1. Three Axes of Power Grid Models*

Most models today are limited to a single axis of this taxonomy. The three dimensions described above, though, are not independent. Issues raised along one dimension (e.g., an evolution toward more renewable energy generation) affect issues along the other axes (e.g., changing the consequences of a wide-area weather event). One can envision, however, models that span these dimensions in a way that more powerfully and accurately reflect the full systemic consequences of individual events or operational decisions. Such models would greatly improve our understanding of the grids as a system and their response to both normal and off-normal events.

Such a national power grid simulation capability does not exist today. A new initiative could fill this role, but would require a unique set of attributes:

- A multi-scale, multi-data, multi-user, multi-model system in a user-focused venue that allows coordination and interaction among users and stakeholders;
- Continuous improvements and capability enhancement;
- Flexible teaming and alliances; and
- Multidisciplinary tool-development teams.

For a national power grid simulation initiative to be effective, additional requirements would need to be met, including:

- Industry buy-in of the initiative;
- Cooperation among various government agencies responsible for grid operations, oversight, development, and security;
- Access to multiple levels of data, possibly including real-time data;
- Protective data sharing and legal measures associated with data and model access;
- Development of new high-fidelity modeling approaches and hardware to support them; and
- Validation of some model results with industry cooperation and support.

These features can be met through a combination of distributed existing capabilities and new capabilities. Defining the details of these needs will require further study. A national power grid simulation capability could take the form of a single, centralized facility or a virtual, integrated environment. Beneficiaries would include regulatory bodies, electric utilities, trade organizations, model developers (vendors), equipment manufacturers, security agencies, universities, private research and development organizations, and other pertinent federal and state agencies.

## GRAND CHALLENGES THAT A NATIONAL GRID SIMULATION CAPABILITY COULD ADDRESS

A national grid simulator would provide a state-of-the-art capability that would be made available for a wide range of independently funded research projects. Although the capability could enhance existing grid modeling and simulation efforts, there are a number of grand challenges that cannot be met with today's capabilities that a national grid simulator could address.

### *Improvement of existing simulation methods*

A national grid simulation capability could greatly improve current simulation methods. Issues to be dealt with include:

- The usefulness and usability of models,
- Parameter identification and surveillance,
- Solution method robustness,
- Advanced contingency analysis,

- Multiple-physics effects,
- System interdependencies,
- Advanced control algorithms,
- Improved model granularity, and
- Multiple spatial and temporal scales.

For example, a national grid simulation capability could provide new and valuable insights into coordinated multi-site physical and cyber terrorist attacks, solar mass expulsions, and nuclear electromagnetic pulse events—none of which can be comprehensively modeled today at the national scale.

### *Interdependencies of critical infrastructures*

Disruptions in the electric power grid system have consequences beyond the delivery of power to customers. Other critical infrastructures depend on a stable and reliable electric supply. Likewise, operational perturbations in other infrastructures can affect the power sector. Modeling and simulation are needed to understand the full impact of a regional- or national-scale incident on dependent infrastructures, which could include transportation, oil and natural gas, water supply, and communications.

For example, imagine the simultaneous loss of a co-located electric substation and natural gas pipeline junction. The loss of the natural gas pipeline junction disrupts the fuel supply to a gas-fired power generation plant, forcing the outage of a second electric substation. In a typical U.S. urban area, the direct cost of a three-day interdependency outage due to loss of these components would be approximately $150 million. Indirect costs due to supply chain disruptions, non-insured loss of perishable goods, and related losses would also be significant. In addition, key emergency services such as hospitals, telecommunications, and emergency response would be affected.

Recovery plans for a disruption of interdependent infrastructures would benefit from a simulation resource capable of discerning the physical, logical, and functional connections among critical infrastructures.

### *Planning scenarios for the power grids*

Tools are needed to simulate large additions of renewable and distributed power to the grids. Models must deal with the intermittency of these sources, optimize the transmission and resource mix, quantify important metrics (e.g., economics, security, and environmental impact), and assess alternative solutions.

### *Design scenarios for the power grids*

Whereas *planning scenarios* deal with moving forward from our current grids, *design scenarios* work backwards from an imagined idealized grid system. Tools are needed to optimize such design scenarios. The goal would be to develop a vision and operating principals for an ideal grid system and a strategic plan toward achieving it.

# IV. Issues to be Resolved

Development and implementation of a national power grid simulation capability would have to address several issues that have, so far, inhibited such an initiative. This chapter aims at highlighting these issues, without drawing conclusions on the degree of difficulty or likelihood of overcoming these obstacles.

## DATA

Modeling algorithms and results can be improved when additional or better data are available. Barriers often exist, however, that limit the availability, suitability, and unrestricted use of data.

### *Data Sources*

Several sources of data are often available for a given power grid model. The quality of data depends on its source. Publicly available data, for instance, is often less complete than industry-maintained data sets.

#### Open public sources

Non-government, public sources of utility information, generating statistics, and generator availability data exist. Few data sets are widely distributed, however, on detailed and current distribution system parameters.

Edison Electric Institute (EEI) collects and provides general capacity, generation, fuel mix, emission reductions, customers, sales, revenues, financial performance, and transmission information. Among others, the American Public Power Association and North American Electric Reliability Corporation (NERC) provide limited data. However, no public source of information is sufficient and accurate enough to support complex electric simulation models that address dynamic transient stability concerns.

#### Government agencies

National laboratories often aggregate various individual data sources and provide data validation and conflict resolution in collaboration with industry or data-holding partners. Agencies such as the Department of Energy's Energy Information Administration act as repositories and distributors of federally collected data, and in some instances provide services for error checking and validation.

#### Commercial data providers

Many companies collect and sell utility data. They collect mostly public domain data, process it, clean and improve the quality of the data, and then offer it in various forms as a business product. A good example is PennWell's MapSearch program for various types of utility data. Platts and other companies offer utility data for North America and some resources for other countries and regions. The data are often provided as customized datasets formatted for specific simulation software. Nevertheless, commercial data sets alone are not sufficiently complete for many modeling purposes.

#### Manufacturers, owners, and users

The electric utilities and transmission operators are the best sources of power system data. Most of the real-time data are collected by the system control centers in each of the balancing authority areas. The data include equipment inventories, operating parameters, pricing information, and weather data.

Generator manufacturers such as GE provide design data for exciter and generator feedback control systems such as time constants and inertia constants, which are essential for dynamic modeling.

Generation companies, transmission operators, and utilities have understandable sensitivities about the release of their data to competitors, regulatory agencies, and the public. Industry is also concerned about control of data that could aid malevolent attempts to disrupt power. Furthermore, FERC regulations bar the interchange of certain data between the reliability/operations and marketing organizations within a utility. The company would have, in fact, a statutory responsibility to ensure that this rule is not violated by its participation in a national power grid simulation effort. A national simulation initiative would need to address these concerns before industry data sharing is possible.

Certainly, industry-supplied data are best for most modeling and simulation applications. Nonetheless, policymakers and the research community can make use of representative data sets in which the proprietary or utility-specific data have been translated into representations that do not allow recovery of the original data or source information. Therefore, though a national power grid simulation capability would need to rely on industry-supplied information, many useful analyses can be performed with data sets that are transformed to be more generic.

Caution is needed, however. Evidence shows that source data can often be recovered from masked data sets. Therefore, simple masking or redacting of data will not be sufficient to eliminate the possibility of data reconstruction and reverse engineering.

### Data types and acquisition

Various types of data are required to support power system modeling efforts. The types and uses of data, in turn, dictate the means for acquiring data.

A national power grid simulation capability could foster the sharing of data tagged with metadata and annotations. Metadata consist of additional information that relates, for example, to the ownership, interpretation, and use of the data. Such information would help data use, security, and validation. Annotations to data can be made to assist in data searching and characterization to facilitate collaboration and workflow. Such collaborative "tagging" is becoming increasingly common in science and engineering collaboration environments.

The types of data that need to be collected include:

- Network topology and connectivity among system components,
- Equipment parameters, and
- Anomalous network conditions.

Acquired data can be static or real-time. Real-time data often deal with information that is operational in nature such as voltage, power flow, price, and generation output level. This information is proprietary and requires active collaboration with regional transmission organizations (RTOs), independent system operators (ISOs), and utility operators. Static operational and technical information, on the other hand, can often be used for planning and other studies for which historical or steady-state information is sufficient.

The scope of likely models in a national grid simulation initiative will require at least two forms of data. The reliability and emergency response community requires real-time data or at least data that are frequently updated. Quality assurance for that type of information is a high priority. Research and planning efforts, in contrast, require only representative data sets that are recognized as realistic, but have minimal updating and quality assurance requirements.

### *Access challenges*

The process of collecting, validating, formatting, representing, and managing data demands significant effort and incurs significant expense. The effort needed to maintain key data sets will ensure that data costs will be a substantial fraction of the overall costs of any national modeling and simulation program. These costs would need to be accounted for in grid simulator start-up and operational costs. By building reference models and data sets tailored to specific applications, and by leveraging publicly available information—especially during model development—a national grid simulator can reduce costs. Nevertheless, many models will ultimately need to incorporate industry-supplied data.

### Free and unprotected data

Data that are obtained without cost or restriction may be freely available for distribution to others. Data found in the public domain are generally not detailed or accurate enough, may have limited scope for modeling efforts, and may not be current enough to support non-static or transient modeling efforts. The application of free data to advanced modeling efforts may have limited applicability.

Nonetheless, public data sets may hold value for verification and validation of closed-source sets obtained elsewhere. Also, the use of public data for research-oriented models eliminates the sensitivity issues of closed-source data.

### Costly and protected data

Data that are available for a cost are often protected in some way to limit their availability to those who have not purchased the data. However, purchased data are generally more detailed and support more rigorous modeling efforts.

### Restricted or proprietary data

The use of some data may be restricted, classified, controlled by a proprietary agreement, or unavailable for other reasons. Providing assurance of responsible use of data requires comprehensive security measures.

As mentioned previously, regulations prohibit the sharing of certain kinds of data within a utility. Also, industry can be reluctant to share data that could lead to negative publicity or unwelcome oversight. Public research activities that make use of a national simulation capability must use models and data that are free of evident utility-restricted data.

### *Data integration quality challenges*

Before data are used in a modeling environment, they must pass through rigorous data validity and quality assurance procedures. The structure and requirements of this process affect model acceptance, validity, and credibility.

Anomalies in grid data and inconsistencies among data sources must be resolved before applying the data. Inconsistencies may exist in data from different sources. A national power grid simulation capability could provide a valuable service by resolving data set discrepancies, especially for data coming from different sources.

The participation of asset owners in the validation of data would be crucial in assuring the credibility of model results.

### *Data management*

Since data formats can vary from model to model, a common data representation within a national grid simulator environment would foster portability among models. In addition, version control would be necessary to ensure spatial and temporal correspondence between simulation results and the data that supported the model formulation.

A national grid simulation capability would likely have a diverse user community, with individuals who have different levels of user authority. For example, data providers may need to follow protocols, such as marking resources as "ready for use" after an appropriate review and development period. Without such approval, data would remain in a review-only status. Mechanisms should be available to data owners and providers to control and limit data usage. In addition, protocols are needed for restricting detailed data from being viewed in aggregate models and their results.

One can envision that certain users would have direct access to the data, including the privileges to change or update the information, whereas other users would have only viewing privileges. Some users would have no data access privileges and would be allowed only to use the models and examine results.

### *Data security and protection*

With the contractual and national security obligations associated with various data sources, physical security, protection, and backup are essential to protect these assets. Moreover, appropriate authorization measures are required to control whether a particular user is permitted to access a particular data source. Access privileges further restrict or permit user data access. For example, modes such as "view only," "edit," or "use without edit and without view" are possible privileges. Access privileges provide the means to distinguish varying levels of control across a broad spectrum of authorized users.

One option for data handling would be for grid simulator users to have access to datasets for conducting analyses without allowing them to view or copy the datasets. Software could be developed to access raw data and prepare customized input datasets. In this way, users could perform customized analyses, but without direct access to raw data. This capability would serve a wide range of users without compromising the integrity and confidentiality of the data.

## MODELS

As described in Chapter III, power grid models are used by a variety of stakeholders for planning, operational support, resiliency assessments, power market analysis, and critical asset assessment. Models and their results drive changes in policy, heighten awareness, provide operational insight, reveal sensitive operating conditions, establish generation levels, direct business plans, forecast market conditions, estimate monetary impacts, and identify operating contingencies and their impacts. A national power grid simulation capability would aid the development of models for use by decision makers and other stakeholders, but would face a number of model-related issues.

### *Model integration*

Power grid models, which can include load flow, stability, short circuit, economic dispatch, congestion, voltage stability, and dynamic stability assessment applications, should interact with each other to make use of data, intermediate results, and other simulation attributes.

Smart interfaces with automated data format conversion can be designed for seamless data exchange to provide interoperability among the various programs and models. Likewise, a mapping of outputs from one model to inputs of another model can be created.

### *Model management*

The administration of various models in different stages of their product life cycle presents many administrative challenges.

Many commercial software products require a license to use the software and its modules. Access to code may require additional intellectual property authorization and licenses, if permitted at all. Within models, various structural issues regarding solution techniques, operational heuristics, and other execution-oriented attributes may be closely guarded to protect vendors from competitive disadvantages.

A mechanism to control software usage by various users is required for appropriate use of software applications that may be undergoing beta testing or that may be restricted from general users. Other users may have their usage limited, perhaps through a general graphic user interface.

Models may be broadly categorized as open source, proprietary, or classified. Therefore, appropriate authorization measures are required for users. Authorization controls whether a particular user is permitted to access a particular model and its capabilities. Once user authorization is permitted, access privileges further restrict model access. For example, "view only," "edit," or "use without edit and without view" are possible modes that can distinguish model developers from users. Classified software tools would require additional layers of protection and control.

A national power grid simulator virtual organization may be served by a comprehensive participant, data, and resource security model. Such a system, as is commonly found in existing distributed virtual organizations such as the Earth Systems Grid (www.earthsystemgrid.org) or the Cancer Bioinformatics Grid (www.cabig.org), can identify and authenticate people, applications, datasets, and computing and storage resources, and can control the datasets and resources that people or applications acting in specific roles can access and the manner in which they can access them.

Software and application configuration and version management enables tracking of various software releases and upgrades, and helps to track the party that is responsible for developing the upgraded versions of the various layers of software that may be embedded in models and applications.

## COMPUTATION

A national power grid simulation capability could take the form of a virtual organization comprising many existing and overlapping real organizations; a diverse set of modeling and analysis tools; a large collection of datasets; a data management system supporting cataloging, annotation, and access control; and a set of both shared and dedicated computing and storage resources.[1]

### *Computing Resources*

A national power grid simulator is likely to require a data management facility that can catalog, describe, annotate, share, maintain, and protect data of varying types, sizes, security levels, and sources. This resource can be centralized or distributed, and can involve the integration of data and metadata catalogs, e-mail systems, collaboration tools (wikis, blogs, etc.), search engines, storage networks, and database systems.

A national grid simulator would provide a wide range of users with the capability for modeling, simulation, and analysis to process existing datasets and derive new ones using a suite of application tools. This resource, too, could be either centralized or decentralized.

A possible architecture for grid simulator computing could be a computing/data network made up largely of existing systems supplemented with some new systems. "Virtual machine" technologies can play a role in enabling virtual organization clusters to run applications on multiple operating system platforms from a single cluster.

Much of the infrastructure needed exists within the national laboratory, university, and corporate communities, and these existing resources could be utilized using grid-based resource-sharing techniques that are in wide deployment today. Motivations for adding new computing resources (clusters and data centers) to a grid simulation virtual organization, however, include:

- Providing extra or dedicated computing or storage capacity to meet the demands and priorities of the user community,
- Meeting security requirements that cannot be accommodated on shared resources, and
- Providing specific machine architecture or operating system environments for application requirements that cannot be provided using existing resources.

### *Networking Needs*

Networking needs of a grid simulator organization would be determined primarily by the degree to which the simulation capability is distributed and by the volume of data transfer required. If highly decentralized, with its major data and storage resources dispersed around the country, a national grid simulator would need sufficient bandwidth from the major national educational and government networks to ship large datasets from storage sites to computation sites at high speeds. The national

"The Anatomy of the Grid: Enabling Scalable Virtual Organizations." I. Foster, C. Kesselman, and S. Tuecke. International J. Supercomputer Applications, 15(3), 2001. www.globus.org/alliance/publications/papers/anatomy.pdf

laboratories and research universities already have such infrastructure in place and utilize it in this manner.

If centralized, a national grid simulation capability would primarily need networking for user access (through remote login and remote graphics display modes) and for data ingestion (from various data sources and grid sensor networks). An intranet based on virtual private networks (VPNs) can make remote access to the network both convenient and secure. Such facilities, too, are already in place at the national laboratories.

### *Collaboration Infrastructure*

Several forms of collaboration technology can be provided to enable members of grid simulator virtual organization to work together, as well as to make the most effective use of data and computing resources. Technologies to consider include:

- E-mail list servers;
- Wiki-like technologies for creating a shared, organically growing information repository, knowledge base, project-wide shared file system, and project web space (all managed with appropriate access controls);
- Unified data annotation and provenance tracking systems that enable all datasets to be tagged with attributes that describe their pedigree and, for derived data, how, when, where, and by whom they were created;
- Unified workflow environments that permit applications, models, analyses, and visualizations to be executed with full provenance tracking on high-performance parallel resources, as needed; and
- Unified data access control systems that allow easy sharing with a fine grain of control over usage and accessibility for all raw and derived data.

## RESULTS AND REPORTS

The distribution of modeling results and reports needs to be carefully controlled, for they could convey sensitive information. This section focuses on these sensitivities by identifying additional access, integrity, validation, version control, security, and protection concerns.

### *Result quality control*

Most validation concerns are addressed while resolving data conflicts or model parameters prior to simulation. Anomalies may, however, manifest themselves during the reporting process. This could spur additional data or model validation or diagnostic efforts to resolve discrepancies and unexpected results.

A provenance trail should be established that describes how all derived data were created; what applications, input datasets, and parameters they were derived from; and how/where/when and by whom they were executed.

### *Result management*

Analysis results and reports require access limitations just as input data do. In addition, measures would be needed to protect datasets that contain data mixed from multiple sources. In some cases, for example, proprietary data may be mixed with non-proprietary data from other sources. Proprietary information must be protected in both the combined dataset and the model results.

Reports can effectively mask the underlying sensitive data and results that are used to generate the report. For instance, regional reports do not reveal underlying individual equipment data that may be proprietary. Reports should conceal information or data that are not appropriate for a particular reader's access authorization.

### *Security*

Reports may contain a variety of data that are subject to proprietary agreements or national security requirements. Physical and logical security and protection are essential to protect results and reports derived from controlled assets.

Because reports may contain data and results that are broadly organized as open source, proprietary, or classified information, appropriate authorization measures are required for users to access reports. Authorization controls whether a particular user is permitted to access a particular report and to review the results and data in the report.

### *Sharing*

Sharing reports and results with others outside the grid simulator user community brings additional management and dissemination requirements. Advance authorization is required for the release of reports to individuals, organizations, or corporations that have not previously completed rigorous vetting.

## ADMINISTRATIVE ISSUES

A national power grid simulation initiative would need to be sensitive to who will have access to the modeling and simulation capabilities and products. Those entities that are granted access to participate in the program will have to be vetted through a confidentiality process, which would include non-disclosure agreements and other controls over access to models, data, and results. The nature of the controls would depend on the level of classification of the information being accessed and generated.

Models, data, and results will have associated intellectual property rights that would need to be protected. Intellectual property rights would vary according to the nature of the funding arrangement between the sponsoring agency and the performer.

Outside agencies and partners sponsoring individual projects using the simulator capability would need to agree to the system of controls set in place. The nature and terms of these agreements and controls would need to be evaluated as a power grid simulator concept is developed.

The development of a national grid simulation capability would require funding for start up, long-term maintenance and operation, and specific analysis projects. Multi-agency support would likely be needed. Such support could lead to conflicts in policy, priority, standards, procedures, and security requirements. These conflicts need to be investigated and mitigated as a grid simulation initiative is developed.

In addition, a modeling and simulation initiative would need to comply with federal, state, local, and tribal regulations in areas such as health and safety, process control, and quality assurance.

# V. Benefits of a National Power Grid Simulation Capability

Although several issues have been identified that would hinder the development and implementation of a national power grid simulation capability, there are numerous benefits that such a capability would provide.

A national grid simulation program would represent an opportunity to attract users from a range of science and engineering institutions, including the electric power industry, software developers, academia, national laboratories, and government agencies. With the breadth of institutions using a national simulator would come a diversity of interests and perspectives and the accompanying scientific and technical rigor that drives innovative, quality research.

The support of a national grid simulator by a diverse sponsor set would promote integrated policy development in energy reliability and national security. The opportunity to develop policies that recognize the intertwined nature of energy and national security policy is both timely and important in today's global political and economic environment.

Despite the hurdles to be overcome, then, the opportunities are great enough to warrant a more detailed study of the potential of a national grid simulation capability to fill some of the gaps that currently exist in ongoing modeling and simulation efforts.

One of the most compelling benefits of a coordinated national capability is that it would allow us to further understand grid data and technology issues through:

- Exploring parameter data for macro modeling and electric system behavior;
- Baselining parameter data for individual system components and their interactions with upstream and downstream components;
- Converting and interfacing data between power models and other infrastructure models;
- Further developing procedures and mechanisms to access and protect modeling data and results; and
- Providing unclassified simulation and analysis output decoupled from classified information.

These are crosscutting benefits for all grid users and stakeholders. A national grid simulation capability, however, would accrue additional benefits for different user communities:

### FEDERAL POLICYMAKERS

- Multi-scale models have the potential to provide analysis of and solutions to *national* concerns as consequences of *regional* and *local* events.
- The simulator could address issues of national scope, such as cyber security, hurricanes, climate change, hydro power dynamics, renewable energy mandates, electromagnetic pulses, the nexus between energy and water, national energy independence, long-term reliability, smart-grid technology implementation, and plug-in hybrid vehicle deployment.
- The simulation capability could explore important interdependencies among infrastructures.
- New models can link operational and security tradeoffs to social and economic impacts.
- The simulator would improve short- and long-term planning for the national power grid system, including the potential for a wholly new, improved, and more resilient power grid system.
- The capability could help optimize transmission and resource mixes (e.g., the use of distributed renewable generation).

### INDUSTRY

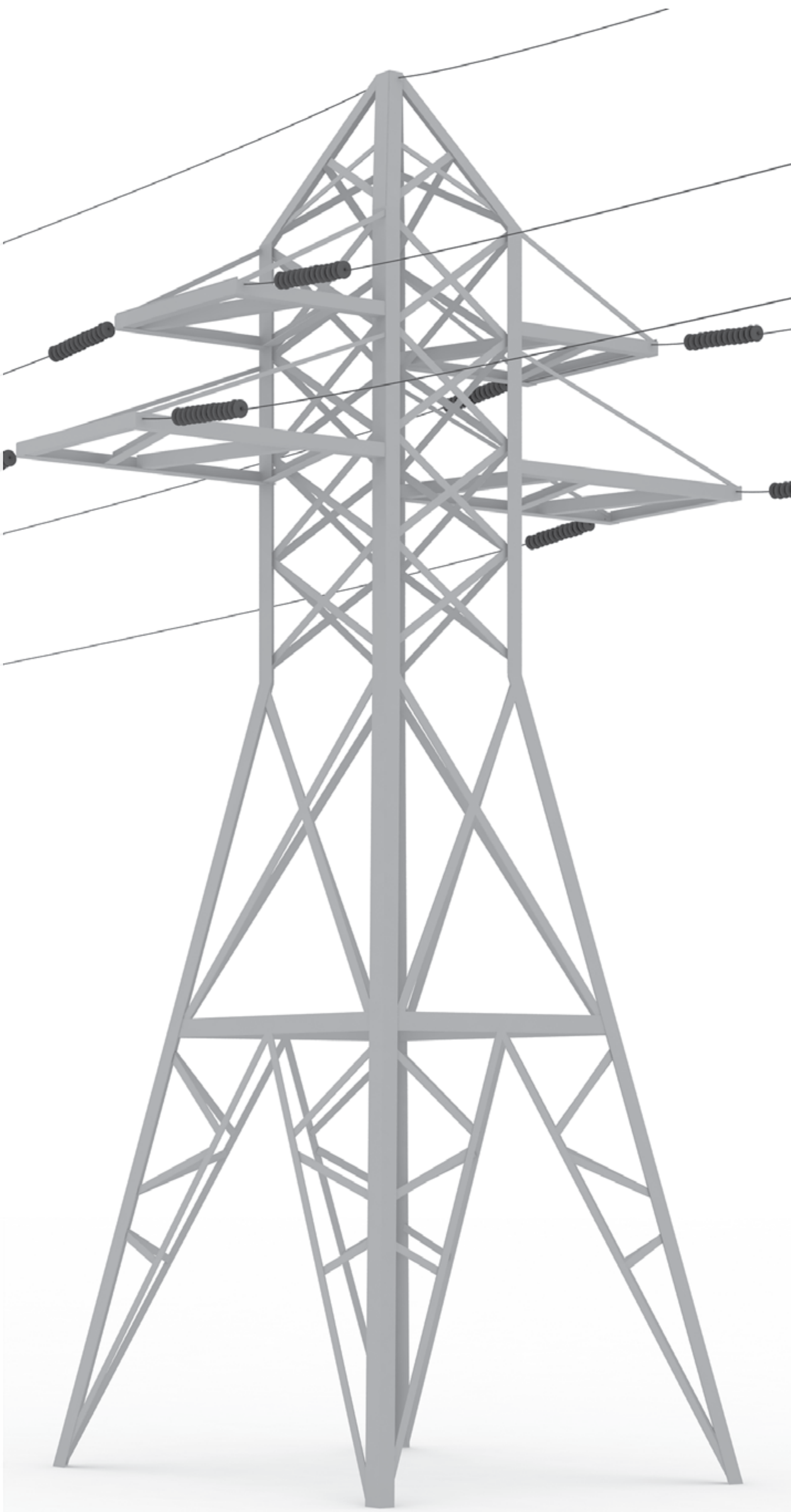
- A national initiative would provide a coordinated way to engage industry stakeholders, to serve their needs and exchange information.
- Transmission companies, including independent system operators (ISOs), regional transmission organizations (RTOs), and utilities, would have a neutral resource for planning at a broader and more strategic national level.
- The capability would provide a deeper integration of infrastructures (e.g., electric, oil and gas, transportation, water/waste, and communications), enhancing the links that already exist among these sectors.
- A national simulator would benefit the movement toward adaptive islanding (temporarily isolating portions of a grid to improve resiliency and efficiency).
- The resource would support industry in its ongoing activities dealing with uncertainty and intermittency and in understanding design trade-offs.

- An integrated capability would help with parameter identification and enhanced monitoring.
- The simulation capability could supplement industry tools for advanced contingency and restoration analysis.
- Advanced power grid control algorithms could be tested.
- Functions and events in various timescales could be better understood. For example, power grid response could be evaluated under three different perspectives: normal operations (seconds to weeks); national-level disruptive events such as cyber attacks, hurricanes, earthquakes, and electromagnetic pulses, (days to months) and; engineering the evolution of the current grid system to a new desired state (months to years).

## ACADEMIA AND RESEARCH COMMUNITIES

- The research community could more readily solve shortcomings with existing modeling methods, adding, for instance, improved robustness and granularity suitable for specific applications.
- A national capability would help standardize validation of data integration and modeling algorithms.
- A national initiative would help standardize metrics related to economics, security, environmental and social impacts, etc.
- The capability would facilitate workforce training and spur interest in students who are considering careers in power engineering, modeling and simulation, environmental sciences, and other disciplines.
- Other infrastructure simulations can be constructed from the grid simulator template.

Costs for a national power grid simulation capability would be small compared to these benefits. The capability could, for example, be applied to the problem of grid congestion, which currently costs consumers many hundreds of millions of dollars annually. Even small improvements in grid efficiency that would come from better modeling and stimulation resources would make the investment cost-effective.



# VI. Conclusions

The National Power Grid Simulator Workshop held at Argonne National Laboratory on December 9 and 10, 2008, examined ongoing and emerging modeling and simulation needs for the U.S. electric power grid system and assessed those needs against current modeling and simulation capabilities at universities and national laboratories. The workshop participants concluded that several national-scale grid concerns and threats cannot be adequately modeled using today's capabilities. Among these concerns are:

- Wide-area disruptive events, including natural events, cascading accidents, and coordinated cyber and physical attacks;
- Interdependencies of the power grid system and critical infrastructures;
- Improvement of existing simulation methods; and
- Planning and design scenarios for the power grids, including wide-scale deployment of intermittent, distributed generation.

Understanding the interdependencies of the electric power grids with other critical infrastructures, in particular, represents a serious unmet need. Disruptions in one infrastructure (such as the electric grid system) can have severe consequences for other infrastructures (such as the natural gas and water supply systems). Modeling and simulation are needed to understand the full impact of a regional or national-scale incident and would help improve recovery measures.

A new national power grid simulation capability has the potential to fill some of the gaps between grid concerns and current modeling capabilities. New modeling approaches could span different applications (operations, planning, training, and policymaking) and concerns (security, reliability, economics, resilience, and environmental impact) on a wider set of spatial and temporal scales than are now available.

To fulfil this role, a national power grid simulation capability would need:

- A multi-scale, multi-data, multi-user, multi-model system in a user-focused collaboration venue that allows coordination and interaction among users and stakeholders;
- Cooperation among various government agencies responsible for grid operations, oversight, development, and security;
- Industry buy-in for the initiative;
- Access to multiple levels of data, including possibly real-time data;
- Protective data sharing and legal measures associated with data and model access; and
- Validation of some model results with industry cooperation and support.

A national power grid simulation capability could be built through a combination of existing distributed and new capabilities. It could take the form of a single, centralized facility or a virtual, integrated environment. Beneficiaries would include regulatory bodies, electric utilities, trade organizations, model developers (vendors), equipment manufacturers, security agencies, universities, private research and development organizations, and pertinent federal and state agencies.

Several issues would have to be addressed, however, in developing and implementing a national power grid simulation capability. In particular, acquisition of and access to validated electric infrastructure data would be a necessary part of a grid simulator initiative. Physical and administrative protection of controlled information would be essential, including protection of sensitive information generated as model output.

Despite these issues, a national power grid simulation capability would provide many benefits, especially as the grid system faces new and growing challenges. In particular, a national power grid simulator would provide the opportunity for data sharing, data verification and validation, identification of data use, and an environment that simplifies the integration of diverse system models. A power grid initiative could also provide a template for eventually addressing a wider set of national issues such as water and waste water, communications, transportation, and other critical infrastructures.

For these reasons, the participants of the National Power Grid Simulator Workshop recommend a more detailed study of the barriers currently inhibiting the development of a national grid simulation capability. An operational plan that overcomes these barriers would set the stage for the implementation of a capability that would go far in supporting a more secure, reliable, and resilient electric power grid system for the nation. A near-term step would be to further engage the electric power industry in order to better understand their needs, capabilities, and concerns.

# Appendix A

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## Appendix C

*National Power Grid Simulator Workshop Program*

| December 9, 2008 Time | Topic | Speaker |
|---|---|---|
| 0830 – 0900 | Registration | — |
| **Introduction** | | |
| 0900 – 0915 | ANL Welcome | Alfred P. Sattelberger, ANL |
| 0915 – 0930 | National Security Motivation | Nabil Adam, DHS |
| **Presentation and Panel Discussion – National Grid Concerns** | | |
| 0930 – 0945 | Introduction to Grid Concerns, Current Activities, and Needs (framing the problem and highlighting example grand challenges) | Michael McElfresh, ANL |
| 0945 – 1000 | Break | — |
| 1000 – 1200 | Panel Discussion: Current Capabilities and Threats; Identification of Major National Challenges | Panel: Henry S. Kenchington, DOE; Nabil Adam, DHS; Pablo Garcia, SNL Loren Toole, LANL; Tom Vandervort, NERC |
| 1200 – 1300 | Lunch | |
| Discussion – Selection of Key Grand Challenges | | |
| 1300 – 1340 | Grid Simulation Research Portfolio – Open Discussion to Select National Grid Threats and Challenges to Guide the Other Breakout Sessions | Moderator: Michael McElfresh, ANL |
| Presentations – Issues to be Faced in Addressing National Power Grid Challenges | | |
| 1340 – 1400 | Models and Computation — Needs, Validation, and Interfacing | Pablo Garcia, SNL |
| 1400 – 1420 | Data and Results — Needs, Availability, Sharing, and Security | Steven Fernandez, ORNL |
| 1420 – 1430 | Group Photograph | — |
| 1430 – 1440 | Break | — |
| 1440 – 1500 | Policy and Legal Issues | Tom Vandervort, NERC |
| 1500 – 1515 | User, Stakeholder, and Sponsor Coordination | Shabbir Shamsuddin, ANL |
| 1515 – 1530 | Objectives for Breakout Sessions | Mark C. Petri, ANL |
| Breakout Sessions | | |
| 1530 – 1630 | Breakout Group Meetings: Organizing Day-2 Activities | |
| Group Reports | | |
| 1630 – 1730 | Breakout Group Reports | Breakout Group Leaders |
| 1730 – 1800 | Break | — |
| Dinner | | |
| 1800 – 2030 | Dinner | Michael Aimone, U.S. Air Force |
| **December 10, 2008 Time** | **Topic** | **Speaker** |
| 0830 – 0900 | Review of Day's Agenda and Open Discussion | Mark C. Petri, ANL |
| Breakout Sessions | | |
| 0900 – 1100 | Breakout Sessions: Discussion of Issues | — |
| 1100 – 1115 | Break | — |
| Group Reports | | |
| 1115 – 1230 | Breakout Group Reports | Breakout Group Leaders |
| 1230 – 1345 | Lunch | — |
| Breakout Sessions | | |
| 1345 – 1545 | Breakout Sessions: Report Writing | — |
| 1545 – 1600 | Break | — |
| Wrap-up | | |
| 1600 – 1715 | Breakout Group Reports | Breakout Group Leaders |
| 1715 – 1730 | Next Steps | Mark C. Petri, ANL |
| 1730 | Adjourn | — |

| Breakout Group | Topic | Leader |
|---|---|---|
| A | Grid Simulation Research Portfolio | Jeffrey Dagle, PNNL |
| B | Models and Computation | Pablo Garcia, SNL |
| C | Data and Results | Steven Fernandez, ORNL |
| D | Policy and Legal Issues | Tom Vandervort, NERC |
| E | User, Stakeholder, and Sponsor Coordination | Shabbir Shamsuddin, ANL |

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